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A PRELIMINARY STUDY OF AN OMNIBUS MAINTENANCE CONCEPT FOR AIR LAUNCHED MISSILES

by

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and

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December 1987

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By the year 2000, the U.S. Navy's inventory of air launched missiles is expected to triple. With the current impetus to reduce Department of Defense spending, NAVAIR (Code 418) has focused attention upon the logistics requirements for air launched missiles and is currently seeking a more efficient, cost-cutting maintenance strategy. Presently in the conceptual stage, a Request for Information (RFI) has been drafted by NAVAIR to be distributed to interested contractors in an effort to determine the feasibility of an omnibus maintenance site. This thesis explores those issues relevant to the RFI and attempts to provide a non-biased structure from which the responses to the RFI may be evaluated.

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A Preliminary Study of an Omnibus Maintenance Concept For Air Launched Missiles

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ABSTRACT

By the year 2000, the U.S. Navy's inventory of air launched missiles is expected to triple. With the current impetus to reduce Department of Defense spending, NAVAIR (Code 418) has focused attention upon the logistics requirements for air launched missiles and is currently seeking a more efficient, cost-cutting maintenance strategy. Presently in the conceptual stage, a Request for Information (RFI) has been drafted by NAVAIR to be distributed to interested contractors in an effort to determine the feasibility of an omnibus maintenance site. This thesis explores those issues relevant to the RFI and attempts to provide a non-biased structure from which the responses to the RFI may be evaluated.

Thesis T-Thesis ...

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I. INTRODUCTION

As the end of the Reagan Administration approaches, fiscal constraints are expected to become increasingly critical. To effectively man and equip its six-hundred ship fleet, the Navy must seek ways to reduce outlays and obligations in every area possible. One of these areas is the subject of this thesis; the configuration of an intermediate and depot level maintenance facility for the Navy's arsenal of air launched missiles.

The decision maker is faced with both near-term and long-range costs. Will he consider the full life-cycle costs or will his view be limited to more immediate concerns? Will he base his projections only on minimizing the next fiscal year's cost of the project, even though such a decision will likely result in an ultimately higher life cycle price tag?

Cost is not the only factor to consider. The decision maker is also faced with such diverse elements as social and ecological impact, the current state of local and national politics and many other facets of the problem which will be addressed in this thesis.

Tradeoffs exist at every decision point. From an economic perspective, the decision maker must choose between the amount of utility he is sacrificing to reduce his costs

by each monetary unit. With regard to DoD effectiveness, it is extremely difficult to measure utility in the form of dollars. For example, how does one begin to quantify deterrence? Can or should it be measured in dollars or is there another, more appropriate yardstick with which we can make an optimal decision?

One method of quantifying deterrence is with the use of readiness. The Navy uses readiness figures for virtually all of its operational quantification. For missiles, readiness is computed as follows:

$$\text{Readiness (\%)} = \frac{\text{Number of RFI missiles}}{\text{Total missile inventory}}$$

where total missile inventory is that number set by CNO directive, or actual inventory, whichever is lower. [Ref. 1]

It is assumed the decision maker seeks an optimal solution. However, he may be forced to sub-optimize at the component level in order to obtain the best final product/service or, if he optimizes each component, he may be left with a sub-optimal system. This concept also applies in the macro sense. The government may need to sub-optimize each weapon type in order to optimize the overall Navy mission requirements.

A. BACKGROUND

Naval Air Systems Command (NAVAIR) is responsible for all air launched missiles within the Navy's inventory. This

inventory currently includes: HARM, HARPOON, PHOENIX, SHRIKE, SIDEWINDER, SPARROW, STANDARD ARM, TOW, and WALLEYE. As the following systems come "on line", they will be included with the above: AMRAAM, HELLFIRE, MAVERICK, PENGUIN, SKIPPER, and SIDEARM. [Ref. 2: p.1-1-1]

Following the maintenance concept of naval aircraft, missile maintenance is performed on three separate levels: organizational, intermediate and depot. Reference 2 imposes limitations on the extent of maintenance each of these levels is allowed to perform.

The lowest level of maintenance is the organizational level or O-level. This is the maintenance performed by the individual ship or squadron and is basically limited to the procedures necessary to maintain the equipment in an operational status. On missiles, this effort consists primarily of removing the missile from its container, conducting a visual inspection, installing the flight control surfaces and attaching the missile to the aircraft. No repair work on the missile proper is performed at the O-level.

The next tier is the Intermediate level, or I-level. Maintenance performed at this level includes inspection and testing of the All-Up-Round (AUR) to determine its readiness for issue to the fleet, replacing major sub-assemblies and very limited work on individual components. As this thesis is written, all intermediate missile maintenance is

performed at the Naval Weapons Stations at Concord, California, Fallbrook, California, Yorktown, Virginia, and Missile Maintenance Unit I in the Republic of the Philippines. For the Navy's missile inventory, I-level maintenance consists of removal and installation of such items as the guidance control section, warhead or engine sub-assemblies. Work on these sub-assemblies is not currently performed at the I-level.

The most complex level of maintenance is the Depot. Here, the sub-assemblies are inspected, tested and repaired down to the faulty component. It is at this level that the decision to rework the part or replace it is made. For missiles, the Depot does not fully assemble the weapon, but returns the repaired sections to the Intermediate level. It is the job of I-level to assemble and test the missile as an AUR. This level will then issue it to the fleet for use. The Naval Aviation Depots, or NADEPs (formerly known as Naval Aircraft Rework Facilities or NARFs) at Alameda and Norfolk are currently the only organic facilities that perform missile depot-level maintenance. These facilities accommodate the Sparrow, Sidewinder, Phoenix, Shrike and Harm. Depot-level maintenance for the remaining missile systems is performed by the prime manufacturers at their facilities located throughout the country.

An additional facility, Missile Maintenance Unit One (MMU-1), is located at Cubi Point in the Philippines. The

function of MMU-1 is analogous to the weapons stations. However, MMU-1 is located near the advanced deployed units in the Pacific and Indian Oceans and can screen and repair fleet returns with greatly reduced transportation costs and missile down time. A second MMU, to be located in the Mediterranean, is under study.

Early in 1987, NAVAIR (Code 418) was directed by Assistant Secretary of Defense for Shipbuilding and Logistics to study the possibility of combining the intermediate and depot level maintenance facilities under one roof, either at a naval installation or at a contractor's plant. This idea was conceived as a cost cutting measure by reducing capital investment and as a means to help reduce turn around time of missiles. In order to comply with the Competition In Contracting Act, NAVAIR is considering suggestions from both government contractors and its organic facilities. At the time of this writing, a Request For Information has been advertised to allow interested parties the opportunity to provide inputs to the decision maker. As currently planned, these participants may compete under the full and open competition premise of government procurement.

Mr. Lyle Hochberger, Associate Director of the Weapons Support Directorate for the Pacific Missile Test Center, contacted Professor Dan Boger of the Naval Postgraduate School in the spring of 1987, suggesting several thesis

opportunities regarding the missile maintenance concept. Several students have undertaken different facets of the problem, our work being one of them.

B. PROBLEM DEFINITION

It has become apparent from the interview process and the Request For Information that five basic decisions should be made before the formal Request For Proposal can be initiated. The decision maker must determine: 1) to what degree will capital assets be owned by the government, 2) to what degree will commercial staffing be employed, 3) the number and location of the proposed sites(s), 4) the degree to which a common core of test equipment is technologically and economically feasible and 5) which aspects of the intermediate/depot level maintenance concept might be combined to increase efficiency.

Figure 1 is intended to provide a quick grasp of the numerous alternatives available to the government for the missile maintenance concept. It has intentionally been over-simplified for illustrative purposes. In reality, many choices will likely present numerous intermediate decisions.

For example, the choice between one central test bench for all missiles and a separate test bench for each missile type could be expanded to include the choices of two or three test benches tailored for missiles of similar construction or characteristics. As each new choice is

```
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                           MULTI SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                  GOVT OP
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                          SINGLE SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
   GOVT OWNED-
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                           MULTI SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                    KR OP
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                          SINGLE SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D

                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                           MULTI SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                  GOVT OP
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                          SINGLE SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
     KR OWNED-
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                           MULTI SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                    KR OP
                                       CENTRAL TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
                          SINGLE SITE-
                                         MULTI TEST BENCH /COMBINED I/D
                                                          \SEPARATE I/D
```

Figure 1. Simplified Depiction of Alternatives

included in the model, the number of end alternatives increases exponentially.

Figure 2 demonstrates a possible means of assigning costs to each alternative. The amounts have no basis in reality and are simply intended to show that, with each alternative, individual component costs will vary. For instance, the development of a new, multiple missile maintenance facility will likely incur acquisition and operating costs much different from those of a single missile facility. The additional choice between a

			TEST EQUIP	MILCON	ETC.
MULTI SITE	CENTRAL TEST BENCH	COMBINED I/D	\$12 MIL	\$2 MIL	
		SEPARATE I/D	\$2.3 MIL	\$6.2 MIL	
	MULTI TEST BENCH	COMBINED I/D	\$1.8 MIL	\$1.7 MIL	
		SEPARATE I/D	\$.8 MIL	\$3.3 MIL	
SINGLE SITE	CENTRAL TEST BENCH	COMBINED I/D	\$36 MIL	\$2.2 MIL	
		SEPARATE I/D	\$14 MIL	\$2.5 MIL	
	MULTI TEST BENCH	COMBINED I/D	\$6 MIL	\$3.4 MIL	
		SEPARATE I/D	\$7.8 MIL	\$5.1 MIL	

Figure 2. Component Costs Per Alternative

government owned facility and a contractor owned facility adds another dimension which may affect each cost factor in differing degrees.

C. SCOPE

The intent of this thesis is not to recommend a particular facility configuration. It is intended to qualitatively define the problem confronting the decision maker and discuss those variables having the greatest impact upon the solution. Much data currently exists on many of the variables mentioned throughout this study and the reader will be directed to appropriate sources of information which will amplify each point.

D. METHODOLOGY

The thesis research consisted mainly of interviews with Naval Air Systems Command (NAVAIR) Code 418, Naval Weapons Stations, Naval Aviation Depot (NADEP), Pacific Missile Test Center (PMTC) and civilian contractor personnel. During these interviews, opinions from various people were gathered and digested. We have attempted to express the more notable suggestions of these people within this thesis.

Weapons stations interviews were conducted at NWS Concord, NWS Yorktown and NWS Seal Beach (Fallbrook). The NADEPs we visited were at Alameda and Norfolk.

Contractor personnel were interviewed from the McDonnell Douglas facility in St. Louis, Missouri. This corporation

was selected because of its extensive involvement in the Harpoon weapon system. Not involved in air launched missiles, but another source of missile information was the Lockheed missile facility located in Sunnyvale, California. This plant was selected because it has enjoyed a long involvement in the Polaris/Poseidon/Trident missile system and it possesses some similarities with the McDonnell Douglas plant.

E. PREVIEW

This thesis is divided into eight chapters. Chapters II through VI address five major decision areas selected because they appeared to be the most commonly mentioned elements of the problem during the interview process. We have attempted to logically present the significant attributes for the decision maker to consider within these chapters.

Chapter II compares and contrasts the major factors involved with the issue of a government versus a contractor owned facility.

Chapter III is a follow-on to Chapter II in that it discusses the facets of a government versus contractor operated facility.

Chapter IV lists the pros and cons of a single site versus multiple sites for a repair facility.

Chapter V presents a discussion of test equipment. In this chapter, the considerations of using a central, omnibus test bench or selecting off-the-shelf components to configure test sets for each missile system are included.

Chapter VI explores potential advantages and pitfalls of using a combined intermediate/depot level facility.

Chapter VII discusses the initial steps that the decision maker should take in determining costs for comparison of alternatives.

In Chapter VIII, a summary is provided of the essential points of this thesis and conclusions and recommendations are presented which should help the decision maker arrive at a more informed choice among available alternatives.

II. GOVERNMENT OWNED VS. CONTRACTOR OWNED

The decision that will profoundly affect subsequent choices is the extent to which the proposed maintenance facilities and capital will be owned by the government. From a cost standpoint, the issue shares many elements of a classical "make or buy" decision. However, considerations such as military construction time lag or determining sufficient surge capacity must be taken into account. Furthermore, the choice is not necessarily restricted to a totally government owned or all commercial facility. It is conceivable that land and buildings may be government owned while each manufacturer maintains and operates or leases his own test equipment.

A. CAPITAL INVESTMENT AND CONTRACTOR RISK

Any equipment or buildings which are unique to the maintenance facility will ultimately be funded by the government since such property will have little benefit in any other application. In the event that a commercially owned facility is chosen, the contractor will likely include these capital costs for the project in his bid. Furthermore, unless the government is willing to guarantee that the contractor's costs for such capital will be offset during the term of the contract, one can expect a risk

factor to be included in the bid price. Test equipment which requires new and undeveloped technology will substantially compound this risk element. An additional concern is manufacturing equipment flexible enough to adapt to differing missile technology.

On the other hand, contractors who currently own test equipment or can assign under-utilized production related equipment to maintenance work can offset capital investment risk proportionately. Additionally, assets that are easily converted to commercial use or maintain high salvage value will minimize risk.

B. NEW FACILITIES CONSTRUCTION

Assuming that some degree of new construction will be required for the prospective maintenance facility(ies), the following related issues should be addressed.

1. Milcon Time Lag

Due to the DoD funding process, any military construction will likely suffer a substantial time lag [Ref. 3,4: p. A-6]. Typically, contractors are much less restrained in this regard in that they can quickly fund high priority projects through bond/stock issues or long term borrowing. However, profit motive and risk of contract termination will not influence the configuration of a government owned facility.

One other method is available to avoid the Milcon time lag. With this option, the contractor would build the plant and at the end of the contract period, if advantageous to the government, ownership could be transferred.

2. Phased Expansion

A possible means of reducing system life cycle costs is a strategy of phased expansion. Aggregate missile volume is planned to triple by 1997 (Figure 3) and as inventories age, increased maintenance requirements can be expected.

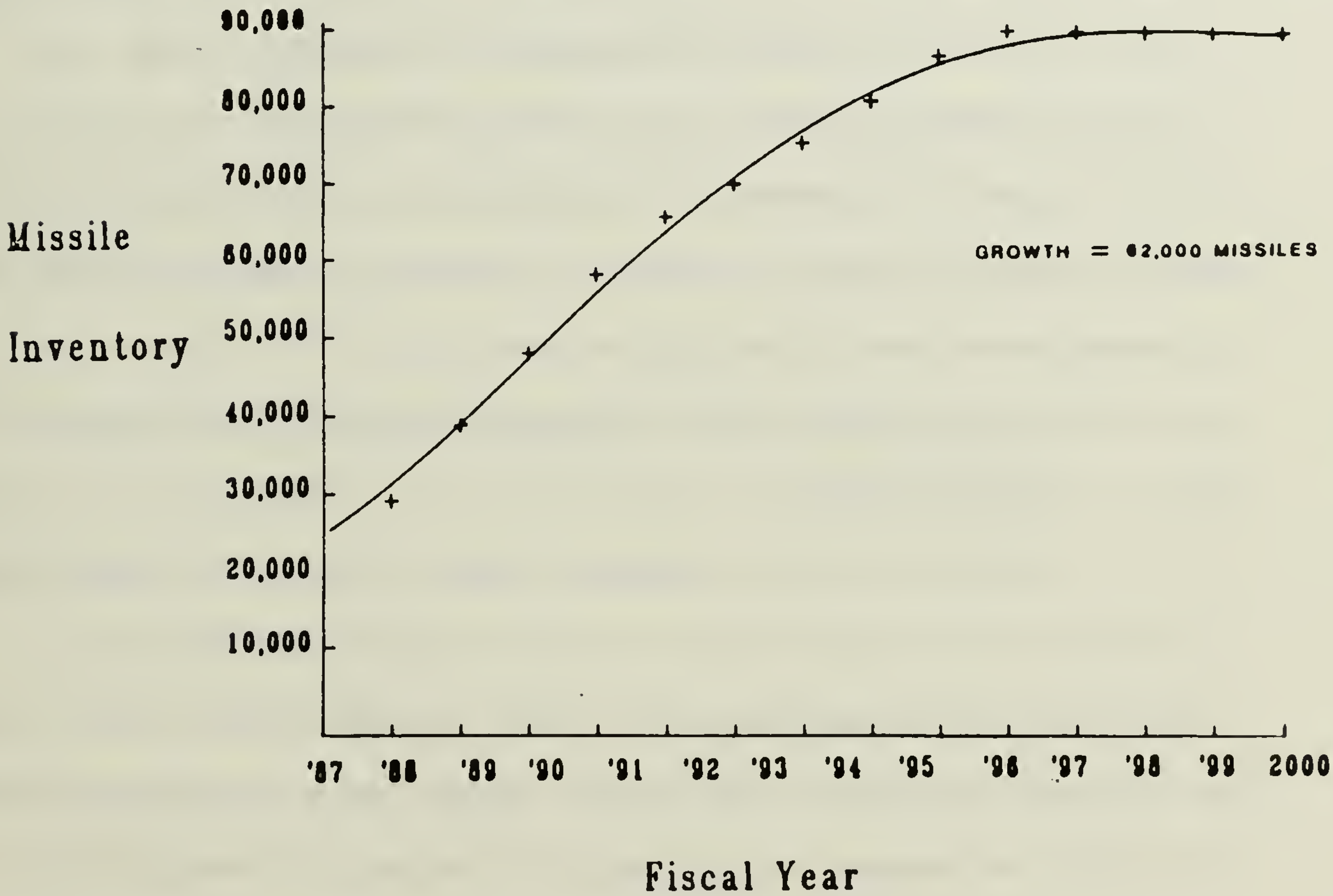

Figure 3. Missile Inventory Growth to Year 2000

For these reasons a large scale facility (or number of facilities) is ultimately indicated. Numerous factors, such as unexpired warranties, insufficient or nonexistent Technical Data Packages (TDPs), etc., suggest that the transition of all missile systems to the new maintenance facility(ies) at one time is unlikely. Therefore, construction of a facility that is designed to accommodate all missile work from day one will likely experience a lengthy period of under-utilization and opportunity costs[1] from idle assets. Some increase in initial construction costs can be expected by designing buildings that are readily expandable or test benches that can accommodate future missile systems. Nonetheless, long term system life cycle costs can be reduced by such measures, provided the planned workload is actually realized.

3. Centralized Use of Existing Production Support Facilities

Installations such as NADEP Alameda or NADEP Norfolk have various facilities available which can be used to augment missile maintenance. For example, each site has existing paint and sheet metal shops used exclusively for aircraft maintenance. Except for highly specialized painting procedures (such as those employed for the Harpoon), economies of scale may be realized through the

1 An opportunity cost is the cost of the next best alternative to which the given resources can be put. [Ref. 24, p. 129]

expanded, centralized use of these shops. If their use by a civilian owned facility is contemplated, accounting procedures for work performed will have to be established.

4. Non-Production Support Elements

Consideration should be given to support elements which are not directly related to production. This would include proximity to firefighting units, security, transportation systems, etc.. Each of these systems exist at DoD sites where missile maintenance is currently conducted.

a. Ordnance Firefighting Capability

Firefighting units at naval air stations and especially DoD weapons facilities are specifically trained to handle fires involving ordnance. Since they are already established, little, if any, additional cost would be incurred by their expanded role. In contrast, a civilian plant may be required to establish this capability to meet insurance and safety requirements.

b. Security

Security at naval air stations and weapons facilities can be changed as needed. In addition, military installations are manned and equipped to counter terrorist activity and larger scale threats.

c. Access to Transportation

Naval air stations and, to a lesser extent, naval weapons stations can provide immediate access to air

transport. Strategically, this may be a crucial feature in the event that rapid replacement of fired rounds becomes paramount. Furthermore, naval air stations and naval weapons stations are generally located adjacent to deep water ports, thus providing additional logistical advantages.

5. Commercial Management Implications

If the facility(ies) is(are) to be contractor operated under an ongoing competitive bid process, government ownership of the property will greatly simplify the turnover of operations between two commercial firms. Otherwise, reprocurement and transfer of assets to the assuming contractor must be negotiated each time a change occurs. If the facility were contractor owned, relocation to a new site may be required when a new contract is awarded. The new geographical location of the entire operation could substantially affect the established work force, since new employees would need to be hired or, if workers were retained, they would have to be moved to the new site. Additionally, new transportation networks must be developed to provide for proper delivery of material to the new site.

C. CONCLUSION

Ownership of the maintenance facility is an obvious long term choice that must be made only after a thorough analysis

of the situation has been conducted. In this chapter we have presented a few of the more important concerns (both strategic and economic) the decision maker must include in his analysis. Investment, risk, plant expansion planning, movement of the facility during contract change and peripheral support capabilities are some of the topics discussed.

Chapter III continues this line of thought with the facets involved in the operation (whether government or contractor) of the facility(ies).

III. GOVERNMENT VS. CONTRACTOR OPERATED

Very different from, yet related to, the discussions presented in Chapter II is the contrast between a government operated and a civilian operated facility. Several major differences exist between the two management philosophies of operation. This chapter will attempt to address these major differences.

A. MANAGEMENT STRUCTURE

1. Tiered or Flat Structure

Perhaps the most obvious difference between the government and civilian community is the method by which the organization is structured. In the civil service, the management hierarchy tends to be vertical, with several layers between the bottom and the top of the organization. This system is highly centralized, with the major decision making authority resting with one, or at most, very few individuals. Government organizations emphasize conformance to regulations, not profit. This type of concern, although capable of keeping tight controls on all operations, may be slow and bureaucratic when decisions must be made. [Ref. 5: p. 314]

Many civilian organizations, in the interest of efficiency and profit, have reduced the number of management layers, flattening their tier structures, with each manager

directing the efforts of a larger number of people. Due to reduced numbers of management and supervisory personnel (and, therefore, lower overhead costs), this organizational makeup can be quite advantageous from a business sense. Drawbacks, however, include the increased degree of training and experience that individual workers must possess to be effective. Since the manager must direct a larger number of people, he has less time to train and educate the employees in their individual tasks. Therefore, personnel who possess the competence to function as managers of large numbers of workers (floor level personnel) in a flat tiered organization will naturally command a higher salary.

2. Bureaucracy and Flexibility

The less bureaucratic nature of many commercial firms allows them to respond rapidly to a changing environment or new requirements placed upon the firm. On the other hand, the DoD organizational structure, whose makeup typically is highly vertical, tends to be cumbersome, since many levels of management may become involved in even trivial decisions.

If changes to a contract are required, the contractor has the capability to rapidly respond to those changes. Naturally, he will likely require a contract modification. This adds administrative costs and delays for both from the government and the contractor. Very seldom will a contractor change his process without passing these

costs on to the government. On the other hand, if a change is necessary with a government operated facility, the Navy has the power to direct the activity to make the change without immediate concern for contract renegotiation [Ref. 6]. This allows the government to save the costs of contract modifications, but it also will entail added administrative burdens.

B. EMPLOYMENT AND LABOR

1. Model Employer

The Civil Service System, although relatively parallel to its non-government counterparts, is required to conform to many regulations and procedures not encountered in private enterprise. The government is considered a "model employer" and, as such, must hire individuals who meet minimum qualifications [Ref. 6]. This is not to say that all civil service personnel are minimally qualified. However, commercial firms exercise considerably more leeway when hiring and may hold a position open until the "most qualified" person applies. Once again, a trade-off is encountered since this more qualified, and presumably more productive, worker will require higher wages.

Another disadvantage of DoD hiring policy is the government's inability to easily terminate less productive employees. One recent termination case took several months to settle, requiring many man-days of effort from

management; time taken away from production [Ref. 7]. The hidden costs of lower productivity, increased management workload and other costs are difficult if not impossible to quantify, yet they can be substantial. Though a private company under government contract must also meet certain criteria prior to letting an unproductive employee go, it is somewhat less encumbered and can usually respond in a much more rapid manner than the above cited example suggests.

2. Pay and Benefits

Although the WG (Wage Grade) pay scale is roughly equal to compensation[2] in the private sector for comparable positions, the WG system is more structured and less susceptible to the whims of the economy. Pay raises are regular, but they usually lag behind those given in private enterprise. This slower reaction time has its obvious drawbacks, but these are offset by the greater job stability attributed to government service. This stability factor tends to reduce the turnover rates of more stable employers, the Civil Service system being one of them. However, it is possible that this job stability would have an inverse relationship with worker motivation. By this we mean that as a worker feels more secure in his position, he may

2 The Wage Grade pay system is set by local prevailing union wage rates. Periodic surveys of the local economy are conducted and the government's pay of the WG worker is adjusted based on the results of these surveys.

experience less incentive to increase his job knowledge and/or attempt to increase his own productivity.

3. <u>Union Relations</u>

Strikes are a constant threat in the civilian economy. Although the ability to strike has numerous advantages and has often brought constructive changes to the workplace, this right must be forfeited by the civil service employee. The government has forbidden any government union from conducting strikes or honoring the picket lines of any other striking union.

Since strikes are legal for many non-government employees (even corporations under government contract), the threat or actuality of a strike can completely disrupt the productivity of a facility. This threat to production is a serious drawback in contracting out vital government functions. Especially in the missile maintenance field, unions must be precluded from inhibiting production by means of striking. Although not commonplace, such a situation could have a serious impact on the ability of the Navy to perform its mission by limiting the availability of Ready For Issue (RFI) missiles, and must be considered when dealing with contractors.

C. CORPORATE KNOWLEDGE

As with any manufacturing operation, production procedures or techniques are either not always properly

documented or performed as documented. Missile maintenance is no exception. Consider the following true example. A worker had been performing a certain maintenance function somewhat differently than that prescribed for a number of years because the documented procedure was incorrect. It never occurred to the employee to approach his supervisor about the deviation from the authorized procedure. When the person quit, the replacement was not shown the procedure and his knowledge left with him. When the new worker eventually performed the operation in the prescribed fashion, a batch of the parts failed to pass the quality control inspection. [Ref. 8] This loss of corporate knowledge was extremely expensive.

The situation just described has occurred time and again in industry. This brings home the point that it is extremely difficult to ensure standardized procedures are absolutely correct or are being fully complied with.

Management must be keenly aware of all procedures conducted by its employees and confirm these procedures are proper. If not, the manager should investigate and either change the employee's methods or change the prescribed procedure, whichever is more advantageous to the quality of the final product.

1. <u>Proprietary Information</u>

Difficulties arise when organic entities interface with commercial activities or a new contractor assumes the

maintenance operation. These include patent, copyright and certain other protections afforded to the designer of a product or process. Especially regarding depot level maintenance, the original missile manufacturer may be extremely reluctant to provide other potential competitors with data rights that are necessary for repair work. Although acquisition of proprietary information is possible, there are, inevitably, costs involved to the government. "Even when a contractor agrees to unlimited data rights, securing and maintaining such data can involve substantial resources (costs to the government)." [Ref. 9: p. 5-19]

2. TDP Accuracy and Comprehensiveness

One method the military has used to increase flexibility in contracting, secure proprietary information and ensure corporate knowledge is retained is through the use of Technical Data Packages (TDPs). TDPs are a method of securing either limited or unlimited data rights from the contractor and are used extensively by the government. In many cases, they work very well. However, if they are inadequate, as in the example above, and the government changes contractors, the new contractor will perform to the improper TDP with cost producing results [Ref. 9: p. 5-19]. The government then must rely upon reverse engineering to isolate and correct the problem(s) with the original TDP.

If the government decides to contract out its missile maintenance, it must be certain that all TDPs are

correct and complete. With a DoD facility, TDP problems do not normally occur since proprietary information is not an issue. For more information about data rights applicability and criteria, consult the Defense Acquisition Regulations (Section 9-202.2[F]).

3. First Producer Advantage (Learning Curve)

The original manufacturer of a missile system will naturally possess an extensive depth of knowledge about his product. His learning curve has "leveled off" and, therefore, initial associated costs are well below what a competitor could offer[3] [Ref. 10: p. 17]. With a change of contractor, the costs of a new vendor's steeper learning curve will ultimately be absorbed by the government, both in higher unit cost and, possibly, in an increased failure Rate. These costs can be extensive and must be considered.

D. SUPPLY SUPPORT

Supply support ramifications for a contracted missile maintenance facility are extensive and are covered in depth in a thesis written concurrently with this one by Lcdr. John Ripperton, USN. However, we will address a few of the more significant concerns obtained during our interviews.

1. Supply Priorities

The Navy's supply system is enormous and that portion supporting air launched missiles is relatively

3 This situation is also true for the first vendor of a maintenance contract.

minuscule. This coupled with the fact that a number of commands (i.e., NADEPs belong to NAVAIR and are supported by the Aviation Supply Office or ASO; I-level maintenance belongs to NAVSEA and is supported by the Spare Parts Control Center or SPCC) are responsible for the success of air launched missile maintenance tends to reduce the priority given to the supply support effort. [Ref. 11] As a result, maintaining an adequate supply of spares or providing a timely reaction to urgent requisitions from various Navy facilities is a continuing problem and could be extremely expensive if unavailability of spare parts impinged upon a civilian contractor's operation.

2. Tailored Supply Support

The source of difficulty mentioned above has been addressed by McDonnell Douglas, which has developed a separate supply system for its depot level maintenance of the Harpoon. The company developed a model called "Depot Stock Allowance List" (DSAL), which is a spares management system that identifies and calculates spares requirements for the Harpoon depot facility at the McDonnell Douglas St. Louis, Missouri plant [Ref. 12]. Such a system is dedicated to serving only one "customer" and, as such, can respond rapidly to changes in demand from that customer and the order does not get "lost in the shuffle", a phenomenon experienced frequently with organic facilities maintenance. [Ref. 13]

Although this tailored system is extremely efficient and attractive, such a supply support concept carries a price tag [Ref. 14]. Again, the decision maker must choose between a highly effective arrangement at a premium price and the existing system; more cumbersome, but at a far lower cost[4].

E. CONTRACT TYPE

If the Navy decides to conduct its missile maintenance on a commercial basis, contracting considerations will be crucial. Although normally handled by the contracting officer, all decision makers must be aware of the benefits and drawbacks associated with each choice that the contracting officer makes.

The Competition in Contracting Act of 1984 established current government policy which is to migrate toward a cost type contract for a fixed price contract as quickly as possible, usually prior to the Milestone II decision (authority to proceed to the Full Scale Engineering Development phase) for new start systems [Ref. 15: p. 1]. Assuming this approach is germane to the missile maintenance facility, the decision maker should consider a fixed price contract from the start. Except for radically new test equipment, very little research and development would be

4 If, however, government furnished spare parts cause work interruptions, delay costs levied by the contractor can be extensive.

involved, allowing for a fixed price contract which would likely lead to lower costs, providing proper incentives are included.

1. <u>Omnibus or Individual Contract</u>

One question that arises is whether to let a single contract for all missile maintenance, or to award each missile type/group as a separate contract. The omnibus concept could allow the government to realize greater cost savings in overhead and perhaps in production costs, due to the realization of economies of scale, whereby outputs increase faster than inputs, decreasing unit cost. However, the potential major disruption to the system caused by a contractor change (resulting from a new contract award) should be factored into such a decision.

2. <u>Duration of Contract</u>

The term of the contract is another important determination. Typically, for reasons of reduced risk and better planning opportunities for the contractor, longer contracting periods tend to lower the overall cost[5]. However, the government must live with the contract, good or bad, for its duration, except in the case of clear evidence of nonperformance (termination for default). Termination for the convenience of the government is a possible

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5 This can be seen by examining investment, start-up, shut-down and learning curve costs, all of which occur only once during the life of the contract.

alternative; however, it is extremely expensive and subject to limitations[6].

a. Get-Out Clause

For some very long term contracts, the government has incorporated a "get-out" clause. This provides for periodic reviews of the contract, and at these times, either party has the option to discontinue the agreement. This allows flexibility to the government to terminate a contract that costs more than is deemed necessary. A good example is a long term contract for computers. As technology improves, more powerful machines are available at far lower prices. With the get-out clause, the government is able to stop the buy of outdated or soon to be obsolete equipment when new and less expensive, state of the art merchandise becomes available.

b. Modifications

Closely related to, but not as drastic as a get-out clause, is contract modification to adjust for changes in technology, such as the example listed above. As always, these options cost the government money. Although modifications and get-out clauses may not be too critical for a service contract such as missile maintenance, they

6 These limitations are: the government must deal in good faith, there must be a change in the circumstances of the contract, and the termination must not be contrary to paramount government policy.

still should be considered by the decision maker when weighing contract choices.

3. Time to Implement

When considering a new firm for the services of missile maintenance, the decision maker should be aware of the extended time period necessary to implement a new contract. Not only is the bidding process itself extensive, the time required for the new contractor to "spool up" can exceed several months with an adverse affect on readiness. [Ref. 16]

Additionally, if government furnished equipment must be moved, excessive time and labor will be necessary to complete the transference of test material. In some cases, the tear down, movement, set up and check out of test equipment can approach one year. [Ref. 17]

4. Measures of Effectiveness

Possibly one of the more difficult facets to quantify is the set of standards the government will choose by which to measure the performance and effectiveness of the contractor. Two of the biggest cost elements found in any measurement procedure are the following:

a. Burden of Proof

The choice must be made as to who will assume the burden of proving performance. Called Alpha or Beta decision error (consumer or producer risk), statistical

sampling can contain subtle differences that may equate to substantial performance variations.

b. Sample Size

Statistically, the larger the sample size, the closer the sample approximates the population. However, sampling costs increase dramatically with the sample size, especially when the test results in the destruction of the sampled items.

5. Incentives

Several methods of providing contractors with incentives to reduce costs, remain on the leading edge of technology and increase quality are currently employed by contracting officers. Such methods include savings sharing, direct reimbursement for beneficial suggestions, or other means to reward the contractor for improvements in his product and are usually written into the contract as either incentives or awards. Many of these could be used in a missile maintenance contract. For example, instead of the contractor replacing a part after it has been reworked only once or a few times, make it more attractive for him to continue to rework the part as long as it is economical, while still maintaining the quality required. This can become a difficult problem since most contractors make a tidy profit on replacement parts and have little, if any incentive to be conservative with reusing worn components. [Ref. 6]

The government can most assuredly gain by providing the contractor incentives to stay on top of technology. Costs can be reduced by employing new procedures or new materials used in the fulfillment of contract requirements. Usage of the various existing incentive or award fee contracts, or the development of a highly tailored method would greatly benefit the government in reduced life cycle costs.

6. Competition and Second Sourcing

The Spending Reduction Act of 1984, commonly known as the Competition in Contracting Act of 1984 (HR 4190) requires, among other things, that the government engage in full and open competition whenever it contracts for goods or services. This means the government must compete rather then single source its commercial business. Missile maintenance is no exception. The decision maker should be aware of the options[7] open to him when attempting to comply with these laws.

At some point, the original contract will expire and the contracting officer must secure another contract to continue operation. Assuming other contractors are interested, they should not be penalized for lack of experience with the work dictated in the contract. Nor should the government be limited to one contractor because

7 An excellent source for many of the contracting options available is Reference 9.

he is the only one who can perform the tasks. To alleviate these problems, the following second sourcing methods should be considered.

a. Leader-Follower

This contract ensures two suppliers. The contractor with the lowest bid is awarded the majority of the work, say 70 percent. The next lowest bidder is apportioned the remainder of the job, in this case 30 percent. Such a system provides the government two benefits. One advantage is that it ensures two contractors are kept up to date with production and therefore enjoy relatively low learning curve costs. Secondly, it provides the government with a wider industrial base and greater surge capacity, should the need arise for immediate production increases.

b. Contractor Teams

With this method, two or more contractors are required to form a team in the development of a project. As the acquisition process continues, the teams are allowed to split and compete with each other, evolving into a system such as the leader-follower described above. This idea might be adapted and a hybrid developed that would serve the government well in the missile maintenance arena.

c. Technical Data Package (TDP)

Discussed earlier in this section, this system requires the contractor to prepare and maintain a data

package that is technically all inclusive and will enable other responsible contractors to perform the job. Although an excellent idea, some TDPs have been plagued with flaws that make the product unacceptable. Since most follow-on contractors are required to perform to the TDP, the government must bear the cost to correct the incomplete TDP (unlike the original contractor, who was required to deliver an acceptable product).

7. Quality Control

To ensure a high degree of quality control, the government has developed several formal quality standards to which the contractor must conform. Among these are MIL-I-45208 and MIL-Q-9858[8]. Naturally, as quality control requirements become more stringent, the cost of the product increases. The decision maker must make a choice in how much quality, and at what price, he will be willing to accept.

If maintenance is to be contracted out, quality control confirmation will be performed by either the Defense Contract Auditing Service (DCAS) or a military Plant Representative Officer (PRO). Consideration should be made for the additional expense this will incur for government administration of the quality program. These costs would

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8 These are not necessarily applicable to missile maintenance, but are mentioned merely as examples of standards available.

not be incurred if an organic facility was employed since DCAS or PRO personnel are unnecessary at DoD establishments.

8. Government Furnished Equipment (GFE)

Ultimately, the government pays for virtually all of the equipment used in its commercial contracts. One advantage of GFE is that the face price of the contract is reduced. This cost savings can be offset, however, by the fact that the government tends to keep and attempt to use obsolete equipment, sacrificing performance and increasing maintenance costs. Old, obsolete equipment should be considered a sunk cost when considering the life cycle cost of missile maintenance contracting. Additionally, delays in delivery of GFE to the contractor can lead to extensive cost overruns.

9. Life Cycle Cost (LCC)

Life cycle cost should be the bottom line for any acquisition. This is not limited to goods but extends to services as well. For a service, however, the LCC factor should be apparent early in the acquisition process; ideally during the request for proposal phase in negotiations.

a. Supportability

LCC takes into account virtually every subject mentioned in this thesis, and includes, but is not limited to, the design aspects of Pre-Planned Product Improvement (P^3I), reliability, maintainability availability and supportability. The first four factors are dealt with in

the product's design phase, but supportability is dealt with extensively in the maintenance of the system. Supportability deals with the capability of the logistics function to maintain a steady supply of parts and services to the provider of maintenance. Supportability is strongly influenced by both the system's maintainability and reliability factors. [Ref. 18]

b. Pre-Planned Product Improvement (P^3I)

Mentioned in the prior paragraph, P^3I is normally a design concept and not usually dealt with in the logistics or maintenance arenas. However, the concept has some interesting dimensions that could be adapted to several aspects of missile maintenance, including test equipment and facilities. P^3I could be employed when considering what test equipment to buy, how facilities will be constructed, and so on. With proper planning, the life cycle cost of the system could be reduced by the employment of a modified P^3I program.

10. Workload

Three ways of addressing workload are Basic Ordering Agreements, Indefinite Quantity Contracts and Requirements Contracts. Each of these give the contracting officer flexibility in determining the amount of work the contractor is required to perform. For example, if an Indefinite Quantity Contract was used, the government has the flexibility to change, at any time, the amount of work it

wishes the contractor to perform. This is beneficial to the government in that it doesn't have to pay for idle time, but it places a burden upon the contractor; he must try to determine how much work will come to him and hire appropriately. Naturally, the contractor will charge a premium for the assumption of such a risk.

Since the maintenance contract may assume many different forms, including the three just mentioned, the Administrative Contract Officer should make every effort to utilize all options available to him[9].

F. PRODUCTION PLANNING

If a contract is let for missile maintenance, the question of how to perform the task will most likely be left up to the contractor. However, the decision maker should be aware of some major factors involved with production planning so that he might isolate any unnecessary costs or recommend alternative methods which would increase efficiency and reduce the costs involved.

Since cost is a primary factor of most contracts, we are, in effect, setting a limit to the amount of readiness we will attain. In today's environment, we must look for the maximum amount of readiness per dollar available to us. Good production planning can help increase that ratio.

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9 These three methods, among others, are discussed in detail in Chapter 3 of Contract Administration, Vol.1, School of Systems and Logistics, USAF,(AU), Wright-Patterson Air Force Base, OH.

1. Inventory

The amount of stock readily available to the production department is one of the biggest concerns of the production manager. "Inventory policies are important enough that operations, marketing and financial managers work together to reach agreement on these policies at the highest levels in many corporations" [Ref. 19: p.443]. If supplies run out, the production line is shut down.

Not only must the actual value of the inventory be considered, but also the additional ordering, transportation and holding costs associated with that stock. The two concepts discussed below, Just-In-Time and Materials Requirements Planning, are proven methods in reducing inventory costs.

a. Just-In-Time

To minimize inventory costs, the Japanese have developed a system called Kan-Ban or Just-In-Time (JIT). Under this system, little or no inventory is held by the manufacturer. Rather, the suppliers make frequent (up to several times per day) deliveries of stock, ensuring continuous production without incurring any inventory [Ref. 20: pp. 130-133]. Timing is critical and suppliers must be reliable for the system to properly function.

b. Materials Requirements Planning

Similar to JIT is Materials Requirements Planning (MRP). MRP is a computer-based system that breaks

down the master production schedule into its elements of raw materials, parts, subassemblies and assemblies needed during a given time interval, determines which materials are in stock or on order, and develops a schedule of orders which will fill the demand during the planning period [Ref. 19: p. 510]. With this concept, all costs are considered and inventory orders are placed in economic order quantities. Each time an order is placed, the quantity requested is such that the aggregate cost[10] of the inventory is minimized.

2. Labor

One of the more interesting concepts to improve both production and worker interest which may be adaptable to missile maintenance is known as Group Technology [Ref. 21: p. 200].

Group technology places workers in teams that perform the entire operation instead of each individual performing one specific task (such as those found in assembly lines). This method allows the worker to see the entire job, from start to finish. In addition to gaining an appreciation for the total work process, he becomes cross-trained in several areas, increasing his flexibility and interest in his job.

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7 Aggregate cost includes all ordering, transportation, holding, stockout and inventory costs associated with the product. [Ref. 20: p. 143]

3. Layout

A properly configured production facility will greatly increase plant efficiency. Ideally, the building will have been designed and constructed with missile maintenance in mind. This will allow design and production engineers to most efficiently plan for production and eventual expansion of the facility, if, as mentioned earlier, an omnibus contract is not initially let.

An integral part of plant layout is where equipment will be placed within the building. Operations Sequence Analysis is an effective tool for accomplishing this task [Ref. 19: p. 340]. The end product of this analysis is an orderly, efficient flow of the product through the entire maintenance function.

G. ACCOUNTING

A major stumbling block in the organic-commercial comparison path is found in the different accounting procedures employed by government entities and commercial contractors. A letter by Dean Merritt of NADEP Alameda stated:

> Cost Accounting practices vary widely between NAVAIREWORKFACs and private contractors. Differences range from fundamentals, such as the definitions of what is direct or indirect to such subtleties as spreading utility costs equally to each direct hour vice making work in machine intensive areas absorb a more realistic share of costs. Additionally, rates for utilities, material and services provided by other Navy activities may not reflect actual cost but are reported by the NAVAIREWORKFACs as actual costs. Cost accounting practices may represent the

> most challenging area to deal with in that the budget cycle cannot be adjusted until the year after the budget year. [Ref. 22: p.2]

Each organization uses a different method of accounting. Although these diverse procedures can be made commensurate, extreme care must be taken when equating the two. The decision maker should know by what means the differences were resolved and ensure the final output of the equation is equitable.

H. UNDERBIDDING

Deliberate underbidding is, unfortunately, a reality and the opportunity to indulge in it exists for both a government facility and the government contractor. The importance of maintaining an equitable bidding arena (by levying penalties on those who deliberately underbid) for both parties is emphasized. Although an absolutely fair environment is unlikely, the current competition process should eliminate, to the greatest extent possible, any advantage enjoyed by either party.

I. CONCLUSION

The length of this chapter tends to indicate the relative significance of the commercial vs. DoD management question. Prices of hardware, buildings and land may be relatively even between the two. Contracting to the best advantage of the government while being fair to the contractor will reap substantial benefits in the long run.

The awarding and management of the contract as well as the other resources mentioned in this chapter will have far reaching effects, both economically and strategically.

IV. MULTIPLE SITES VS. SINGLE SITE

The choice between a single and multiple site facility will have strategic, logistical, and economic implications. If more than one site is considered, the complexity of the decision increases because an attempt to determine both the ideal locations and optimal number should be made. Additionally, multiple site facilities can take on a number of configurations. A particular site may process missiles that share similar test procedures and equipment or the sites may be defined according to the size of individual weapon inventories. A large inventory missile system may consume a single plant's workload whereas another facility might handle several weapon types with smaller inventories.

A. STRATEGIC CONCERNS

An obvious concern regarding a single site facility is that of strategic risk. If the majority of the weapons in the repair pipeline are concentrated at a single point, they become much more susceptible to sabotage or a well placed nuclear strike. Listed below are a number of suggestions to reduce the risk to a single site facility.

(1) Locate the facility centrally in CONUS. This would increase the time available for U.S. defense systems

to react and would decrease the accuracy of enemy targeting.

(2) Incorporate nuclear hardening in the facilities construction. This, of course, will substantially increase the costs of the facility.

(3) Maintain high security to counter sabotage.

(4) Disperse inventory points where queues develop. For example, missiles awaiting inspection and those that have been reworked might be stored in different geographic locations. This option, however, will complicate the management aspects of missile transportation and increase transportation costs.

B. TRANSPORTATION CONCERNS

The number of different sites and types of missiles processed at each site will greatly impact the transportation requirements for the maintenance system. Options range from a single site located in the central continental United States, where transportation routes radiate out to customers and back in, to that of a multiple site system where routes form a complex network of nodes and arcs.

1. Transportation Complexity

Depending upon the configuration of each facility, the multiple site concept will entail varying degrees of complexity in the routing system for missile transportation.

For example, if Naval Weapons Station Yorktown processed all types of missiles, units coming from and going to aircraft carriers based out of Norfolk would travel minimal distances to and from the rework site and require greatly reduced handling. However, if certain missiles were processed only at Fallbrook or Concord, California, as is the case with the Harpoon's I level maintenance, travel requirements are significantly increased. When requirements are added for carriers based in Mayport, Florida, Alameda and San Diego, California, and ten different missile types are involved, the complexity drastically increases.

With the use of computers, transportation routing problems that once took days to solve by hand can now be completed in minutes [Ref. 19: pp.255-266]. Thus, optimizing the transportation network for missiles is not limited by complexity. However, the actual management of a highly complex network can produce added costs. As complexity in the network increases, so does the opportunity for missed shipments, breakdowns and complications due to weather. Furthermore, increased damage due to mishandling can be expected.

2. <u>Proximity to Ship Offload Site</u>

The location(s) of the facility(ies) affect the optimal choices in transportation modes and materials handling equipment. Proximity to a deep water port will offer the advantage of immediate offload (possibly by gantry

crane) from an ordnance carrying ship with direct transportation to the maintenance plant via truck, rail or other methods. Since the weapons will be transported straight to the maintenance facility, handling requirements will be reduced. Weapons Stations Concord and Yorktown and Naval Air Stations Alameda and Norfolk have such advantages. Additionally, they possess the secondary service of currently available rail systems. This asset offers the advantage of alternative modes of transportation. If, however, the facility is located away from a deep water port, the missile may be transported by several modes and carriers within each mode to the appropriate site. This increases the likelihood of damage during overland travel and adds to the probability of damage from increased handling between transportation modes.

3. Trucking Considerations

Plant locations that require shipments by truck will incur increased freight costs, transport time and possible increased damage from the extra handling and movement on the roadways [Ref. 20: p.274]. Additionally, Department of Transportation and union regulations impose limitations regarding the number of missiles per truckload, routes, security, etc. [Ref. 3].

4. Shipping Container Requirements

The multiple site concept will increase accounting and coordination requirements for support equipment such as

shipping containers. Each missile type uses shipping containers specific to that weapon system. Though it is not typically considered an integral part of a weapon, the container that holds the all-up-round or component is absolutely necessary for shipment and storage.

Presently, containers do not remain at the repair facility while the missile is reworked or processed. Some containers are partially loaded with finished missiles and shipped to a user that requires less than a full container. Others will be sent back to the manufacturer to accommodate new production. Still others permanently exit the container inventory when used to ship weapons that have been sold to foreign governments.

Unnecessary delays will occur if the number of containers at a given site is insufficient to hold the number of outgoing missiles or components. Therefore, an accounting system is required for the containers which will become more complex as the number of sites increases.

5. Transport Distance Reduction and Multiple Sites

Since roughly 80% of the missiles due for periodic inspection pass on the initial checkout at the I level facilities, it could be advantageous to maintain I level sites close to where the missiles are offloaded from the fleet [Ref. 23]. For example, if the Serviceable-In-Service

Time (SIST)[11] has expired on a missile that is offloaded in Norfolk, it need not be transported across the country to Weapons Station Concord if the Yorktown facility were capable of recertifying and returning the weapon to the fleet. This would reduce transportation costs and the associated time. Higher readiness figures result since the missile would not waste time in a queue or on a truck, but would be quickly returned to RFI condition.

An even more dramatic savings of this nature is realized through the use of Missile Maintenance Units (MMUs) located in the Philippines and, prospectively, the Mediterranean. The MMU located in the Philippines can recertify a missile without the need for transporting it over 5000 miles back to CONUS. A similar facility whose establishment is proposed for the Mediterranean would also provide this advantage in an area where increased U.S. Navy operations has heightened AUR demand.

6. <u>Availability of Test Equipment at a Single Site</u>

Maintainability and reliability of test equipment becomes more critical as the number of proposed sites decreases. If the test and repair workload per site is increased, the impact of equipment down time will affect a greater number of missiles and, therefore, overall mission

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11 Serviceable-in-Service Time is the period of time between maintenance inspections. Expiration of this period requires that the missile be inspected and recertified at an I level facility before it is reissued for fleet use.

readiness. However, from a cost standpoint, it may be less expensive to pay for increased availability in test equipment by increasing the number of test equipment spares inventory at one site rather than maintain individual equipment, and limited spares inventories at numerous locations. [Ref. 18: pp. 55-56]

C. ECONOMIES OF SCALE

The most obvious economic effect of locating a centralized facility at a single site is the economies of scale that may be realized. Spare parts can be maintained at a single location. Administrative and personnel services can be conducted from single offices and land and construction costs can be minimized. However, as Quade [Ref. 24] points out, beyond a certain point, most systems become so complex that inefficiencies due to crowding, mishandled communications, reduced flexibility, etc. outweigh the benefits. Therefore, determination of an optimal size is indicated.

1. <u>Test Equipment Acquisition Costs</u>

As mentioned above, acquisition of a single maintenance site could eliminate the requirement for a large number of missile test benches which would be necessary to support multiple facilities. However, reliability and maintainability issues suggest multiple spares even if only one test bench is maintained for each missile system at a

single site. If the decision is made to keep a single test bench per missile system, then the cost of acquiring equipment for facilities that handled only one missile type would be essentially the same as that for a single facility that handled all missile types. The real expense will be seen in the case where multiple missile types are processed at many sites.

2. Information Management

Tradeoffs exist regarding the manner in which information is processed. For example, multiple sites will require a more extensive means for tying into existing reporting systems, i.e., Computer Assisted Inventory Management System (CAIMS), while a single site may require only one terminal [Ref. 25]. However, a large, single site facility can be expected to incur higher costs for internal reporting.

3. Facilities Construction

One large facility can reduce the cost of land and buildings on a per missile basis. To illustrate this point, consider the simple construction of a storage area for incoming missiles. Two separate storage lots will require two aisles for materials handling equipment whereas a larger, single lot requires one. The requirements for miscellaneous necessities such as lounge areas and lavatories can be reduced with a single site facility. [Ref. 20: pp. 198-208]

4. Utility Rates

Generally, utilities such as electricity and water can be obtained at lower rates for high use customers. Savings can also be realized through the reduced need for utilities related equipment such as power lines and plumbing.

5. Site Maintenance

Any site that is selected will require scheduled and unscheduled maintenance [Ref. 18: pp. 810-821]. Janitorial services, landscaping, painting, etc., must be considered in the overhead. Vendors performing such services can generally charge less per square foot for larger scale contracts.

D. CONCLUSION

Strategic concerns and economies of scale may, at times, oppose one another. The resultant trade-off choices are difficult, but with thorough analysis, the decision maker can select the option that would be the most advantageous to the government and the taxpayer.

Due to their importance, integrated logistics support concerns have received the most emphasis in this chapter. Logistics support has proven to be a significant factor in the acquisition's life-cycle cost. By investing in a solid logistics framework, the decision maker can ensure maximum productivity at minimum cost.

V. SINGLE TEST BENCH VS. MULTIPLE TEST BENCH

The decision to acquire a single, "one test unit does all" facility or maintain the current separate test bench per missile type concept requires a careful analysis of the technology involved. A single test bench that accommodates all missile types will likely require a costly engineering effort. On the other hand, potential exists for savings in such areas as personnel reduction and test equipment life-cycle costs. However, consideration should not be restricted to the present value savings of a single bench's life cycle costs. One must also analyze the risks associated with hardware and software obsolescence in an environment where third and fourth generation systems come and go within the span of a decade.

A. SOFTWARE CONSIDERATIONS

Presently, each missile system depends to some degree upon software for its testing process. If the multiple test bench concept is retained, it is envisioned that this software will continue to be used and updated as required. From a software standpoint, maintaining this status quo is obviously the least expensive route.

However, when considering a single unit system, several alternatives exist for the development of software. Each

has advantages and disadvantages whose impact will vary depending upon the hardware configuration.

1. Use Existing Software

One possibility is to develop the hardware around software which is currently in use. Since, in the past five years, the trend in the hardware to software cost ratio has changed dramatically from a ratio of 7:1 to a current ratio of 1:9, this could result in significantly minimizing software development costs [Ref. 26]. Secondly, current software is a known product; operational delays due to prototype debugging would be avoided. Thirdly, operator retraining would be minimized if the manipulation of the new hardware is similar to that of the old.

The disadvantage is that the use of state-of-the-art hardware technology will be limited by the existing software capabilities.

2. Design New Hardware/Software System

Another option would be to produce a completely new hardware/software system. This would facilitate the use of emergent technology[12] as well as the opportunity to design in production efficiency. For example, with the recent advances in microprocessor speeds, the time required for some test procedures might be reduced by hours. Or, the

12 Fourth generation software is a prime example. Briefly, it allows the use of natural language syntax for writing queries and programming solutions, better enabling less experienced people direct interface with the computer. [Ref. 27: p. 204]

process of trouble shooting at the depot level might be simplified by developing "artificially intelligent" expert systems. [Ref. 27: p.376]

The obvious disadvantage of this approach is the cost in money and time. The software engineer must understand the expert's heuristic reasoning process before he can develop a functional algorithm. Furthermore, the end product must be suited to the non-expert. Regardless of how much the operation can be simplified, a certain degree of operator retraining would be required whenever the hardware changes.

3. Software Update Capability

Savings may be realized if the software for a new test system is designed to be easily updated. The development of a missile system usually continues through the production phase. From the viewpoint of test equipment software, the missiles in the initial production run may be quite different from later versions. Test equipment software should therefore be engineered in such a way that physical changes to the missile system will not render the test software useless. Considering a hypothetical example, the software menu for the Sparrow test might read:

<<< Choose missile type to be tested:>>>

*** A=Sparrow variant 1

*** B=Sparrow variant 2

*** C=Sparrow variant 3

If the software is written with individual subroutines for each variant, the addition of a fourth variant would be relatively easy and inexpensive. Otherwise, if the algorithm does not employ subroutines, the program must be totally rewritten and will incur additional costs.

Two examples of missiles that have varied are the Sparrow, which underwent a significant transition to solid state components and the Harpoon, which has experienced hundreds of Engineering Change Proposals (ECPs) [Ref. 12, 14]. Though not all changes can be anticipated or are relevant to the testing software, flexibility in the software construction should be maximized.

The same concept holds true for test equipment hardware, although software tends to be much more sensitive to seemingly minor changes.

B. HARDWARE CONSIDERATIONS

1. Reliability and System Capability

Of particular importance to the single test unit concept is the need for high reliability in the test equipment to maintain system capability. Obviously, if a greater percentage of missiles are processed by one test bench, a greater amount of production is halted when the bench fails. Furthermore, a single test unit would, by necessity, be extremely complex and opportunities for the

failure of a system increase exponentially as its complexity increases.

A number of factors contribute to equipment reliability such as component redundancy, quality control of parts, etc., and increases in any factor will boost the cost of the system. [Ref. 18: App. A] The following measures to increase system reliability should be considered:

a. Redundancy

The use of parallel circuitry and standby components would enhance the system reliability. Using two power supplies at the same time, each capable of carrying the load by itself, would be an example of a parallel increase in reliability. The increase could be quantitatively measured, assuming exponential failure rates, as follows [Ref. 18: p. 30]:

$$R_s(t) = 1 - [(1 - R_1(t)) \text{ X } (1 - R_2(t))],$$

where $R_i(t)$ = reliability (over time t) of component_i or the $\text{system}_{(s)}$.

One central processor could conceivably handle the requirements of the test unit. However, a second standby CPU could be used as a backup. The following formula would be appropriate for measuring increases in standby reliability. Again assuming exponential failure rates:

$$R_s(t) = R_1(t) + R_2(t) \text{ X } ((1/MTTF_2) \text{ X } t),$$

where $MTTF_2$ = mean time to failure for the standby component.

Of course, while increasing reliability and thereby reducing maintenance requirements, either strategy will increase the acquisition cost of the test unit. However, this cost may be offset by the reduced need for spare parts inventories for test equipment and fewer production delays will be experienced due to test equipment failure.

b. Compartmentalization

By default, the multiple test bench configuration is compartmentalized. The failure of one test unit, while reducing the overall capability of the system, does not prevent another from functioning. However, this is not necessarily the case when considering a centralized unit. For example, the entire system might rely upon one power supply to serve all of its electronic components. If this were a high failure rate item, a redundant standby power supply could be incorporated as illustrated above. However, another option is to design the system such that smaller, less expensive power supplies are used for each missile type. This differs from the system's parallel redundancy in that the system capability is affected rather than system reliability if a power supply fails. Obviously, the system unit could be compartmentalized to such an extent that it would, in fact, be a multiple test bench.

c. Procurement Specifications

Reliability can also be increased by raising the engineering specifications in the contract for the equipment. Specifications such as mean-time-between-failure of components, raw material composition or other measures of quality would apply. This would have the effect of increasing R_1 and R_2 in the reliability equations shown above and would result in increased system reliability. Any such increases in engineering, material, testing and quality control requirements would substantially increase hardware and spare parts costs.

d. Excess Capacity

The equipment might be designed such that its capacity for test and repair of missiles exceeds normal requirements. In the event that the system fails, the inventory of Ready for Issue (RFI) missiles would be used as a buffer. Once the higher capacity system was again operating, the system would more quickly restore the RFI inventory. An additional benefit of excess capacity is the increased surge capability of the facility.

This option carries the costs of the necessary added inventory as well as its acquisition cost.

2. <u>Off-The-Shelf vs. Custom Equipment</u>

The decision-maker might consider the degree to which he can use standard components in the system's design. Existing generic subsystems are much less expensive than

developing and purchasing small numbers of highly specialized pieces of equipment. For instance, if the test set for each missile type utilized an ordinary micro-computer to process test data, two elements of reliability would be positively affected. First, the system would not necessarily rely upon one complex computer for operation, and secondly, the availability and interchangeability of computers is increased. In addition, logistics support of off-the-shelf items is better than the support found in specialized material.

A potential drawback to this concept is that of integrating the standard equipment into the test system. Though the micro-computer in the above example would be quite versatile for home and business use, the missile test system might well require highly specialized components and the process of configuring standard equipment to do the job could prove more expensive.

3. Processing Capability

The decision to design a centralized test bench such that all missile types can be processed simultaneously or one at a time will present cost tradeoffs.

One possibility is to produce a unit with a central, highly versatile processor and peripheral stations where each missile type would be connected. This would be analogous to a mainframe computer with multiple terminals that operate on a timeshare basis. An advantage to this

concept is that it eliminates the need to setup and tear down the equipment when different missile types are to be processed. Additionally, if a large influx of a certain missile type occurs, other missile types need not wait for processing.

This concept may entail greater costs for several reasons. Each peripheral station will be occupying space whether it is in use or not. Furthermore, materials handling equipment would be required for each station. Finally, a more sophisticated central processor would be required to handle multiple inputs simultaneously.

On the other hand, a system that can only process missile types one at a time would likely be simpler in design, occupy less space and create less need for materials handling equipment. However, setup and tear down of equipment would likely affect the production rate and space would need to be allocated to accommodate the queues of missiles that would develop.

C. OBSOLESCENCE

It can be expected that as non-allied nations develop countermeasures to U.S. missile systems, weapons in the current inventory will either be upgraded or phased out. Furthermore, in the last decade, semi-conductor technology has advanced at an astounding rate. This suggests that the hardware used in the maintenance system should be designed

so that it can be easily expanded to exploit new technology without totally redesigning the system. The following means to incorporate flexibility in the system design should be considered:

1. Plug-in Design

Ideally, as additional missile systems are incorporated into the facility, the test equipment should already be compatible with the new missile system. For example, the software that handles the continuity testing should be capable of adding a new missile system without a total rewrite. This could be achieved if the software algorithms maximized the use of subroutines (abstraction) in their designs. Another possibility, if data is available early enough in the development of the new missile, is to have the software containing the new missile system's test routines already written into the current package.

With regard to hardware, its design should be such that the addition of components for a new missile test system can readily be achieved. A simplified example would be a standardized electronics buss that can accommodate plugs for ten missile test systems. When the eleventh system is incorporated, the buss must be replaced. However, if the buss could accommodate fifteen systems or be expanded, overall costs would be reduced.

2. Modularized Support Gear

Instead of designing a piece of support equipment to handle all missiles, flexibility may be realized by modularizing the support equipment of each missile system. For example, a test stand might be built to support either its own missile type or all missile types. With either configuration, addition of a new missile type would likely require acquisition of a new test stand unique to that missile or modification of the "one holds all" stand.

An alternative that may reduce costs would be to design fittings for each missile type that permit the use of a generic test stand. Benefits would be that only one type of test stand need be designed and, if one stand requires maintenance, a single spare would be interchangeable.

3. TDP Procurement for Future Missile Systems

Investment in a complete Technical Data Package for missile test equipment would facilitate engineering changes required by future modifications. Though there is a cost associated with TDPs (as discussed in Chapter III), it is much smaller compared to reverse engineering or acquisition of a new system.

D. CONCLUSION

This chapter has presented several factors in the selection of an omnibus versus unique test bench situation. Both hardware and software costs were addressed as were the

options of using old or designing new test systems. Additionally, flexibility and reliability of the various components in the system were discussed.

Software costs continue to increase relative to hardware. This chapter has emphasized this and we have pointed out to the reader some of the options available to help minimize software costs without sacrificing performance and flexibility. Software must be compatible with hardware, however, or the system will not function.

Obsolescence is a prime problem, especially when considering digital equipment necessary to conduct many of the maintenance functions on the Navy's missile inventory. The decision maker is cautioned not to expend too many resources on such equipment and its software especially when that material may become obsolete in a very short time frame.

VI. SEPARATE I/D LEVELS VS. COMBINED I/D LEVEL

To help reduce overall costs, one option available to the decision maker is the possibility of combining two or more maintenance functions. This choice brings about several other issues, which are discussed in the following paragraphs.

A. WHAT FUNCTIONS TO COMBINE

One way to eliminate the Intermediate level of maintenance is to integrate all I-level functions into the Depot level and continue the O-level substantially as it is.

1. Omnibus Depot

When considering this all-in-one concept, the decision maker must determine how far down the Work Breakdown Structure (WBS) he wants to go. For example, he might attempt to combine all air launched missile maintenance at a single facility. Or he could classify missiles within groups into "families"; that is, missiles with similar characteristics, such as guidance and control or seeker type, may be reworked at one site.

2. Individual Missile or Missile Group Depot

At the opposite end of the spectrum from an omnibus (all-in-one) repair facility is an individual facility for each specific type of missile. And finally, though at a

greater cost, several depots for each missile type could be constructed, giving the advantage of reduced probability of damage from attack, sabotage or accident.

B. HARDWARE/SOFTWARE COSTS

One of the advantages of absorbing the I-level into the depot level is the reduction in the quantity of test equipment. If the present configuration for maintaining missiles is not changed, increases in the number of I and D level facilities may be necessary to handle the increased planned inventories. By combining the four I-level and three depot level facilities that now exist, test equipment hardware costs could be substantially reduced, depending upon how much redundancy (and therefore surge capacity) one wishes to maintain within the system.

However, one should obviously not concentrate strictly on hardware, but should consider also the software requirements and costs, as discussed in Chapter V.

C. STANDARDIZATION

An important advantage of a centralized maintenance facility is the increase in standardization of test equipment. As the system currently exists, several failures detected at the I-level cannot be duplicated at the Depot. One possible reason for this "unable to duplicate the discrepancy" problem is the variability in tolerances

between various test sets[13] located at different sites. Even though all test sets are frequently calibrated, settings can drift during the equipment's service time causing one set to reject the same data which was obtained and accepted by another, identical piece of equipment. If all test benches were under the same roof, then this type of anomaly could be easily and quickly eliminated by recalibration. Under the current system, a substantial amount of time may pass before a calibration problem between facilities is detected and corrected.

D. PIPELINE DELAYS

One of the major problems encountered by the Navy's air launched missile maintenance system is the time a missile is in the rework "pipeline". Reference 27 was a thesis conducted to help the Navy reduce its maintenance pipeline. One of the major delays encountered in the pipeline was caused by transportation problems. With the Harpoon missile system, the pipeline time has been reduced "by an average of 50 days over a six-month period through January of 1986" [Ref. 28]. This reduction was achieved through the use of a dedicated transportation system. This is a costly but efficient method of providing missile transportation which incorporates a hard scheduled carrier that makes deliveries on preset days of the month.

13 This variability can exist for identical as well as different equipment.

With a combined facility, the pipeline could be further reduced by eliminating the need for a transportation system between the IMA and Depot sites, and by employing a dedicated transportation system between the offload point and the repair facility.

E. MANAGEMENT AND SUPPORT PERSONNEL

Cost savings and reduction of coordination difficulties can be achieved with a combined facility by eliminating duplication in management and various support personnel. Since the combining of I and D level maintenance would require little extra effort, the management structure at the Depot level should require only minimal reorganization with a negligible, if any, increase in personnel.

F. ORGANIZATIONAL DIFFERENCES

The decision maker must be aware that significant organizational differences currently exist between the I and D level management structures and the different SYSCOMS. NAVAIR runs the Depots while NAVSEA is responsible for I level facilities. Additionally, missile maintenance is a small part of the NADEP's (Depot level) business, while it is the whole reason for existence among the Intermediate facilities. Therefore, each entity tends to assign different priorities to its missile division.

At the worker level, basic differences exist between the I and D level of skills exercised by the employees within

each organization. The floor-level work in the IMA is very mechanically oriented, with major functions consisting of missile disassembly, testing and replacement of WRAs, and missile reassembly. It does not involve the product at the component level.

On the other hand, depot level work is highly technical. This includes testing, analysis and repairing WRAs at the component level. It is oriented towards the electronics of the missile and not the mechanics of the weapon.

The skill levels required by each function are quite different and ability to transfer knowledge from one function to the next is extremely limited. When considering these factors, the desired level loading theoretically achievable from combining I and D level maintenance may not be accomplished to the extent desired. Missiles will still come in from the fleet in "batches", causing a "feast or famine" environment at the I level and personnel who work on the depot functions would possess limited ability to assist the I level workers. Even if cross training were possible, union problems would likely occur when management attempts to redefine the workers' job descriptions. In particular, the individual worker would undoubtedly protest if he were required to perform a higher paying task and yet receive pay at a lower rate. The decision must be made as to what wage scale is appropriate for the combined I/D workers, whether it should be typical of O level rates, the more complex I

level rates, or somewhere in between. This question will likely be resolved during negotiations with unions (or perhaps by using non-union employees) before such a combined facility can be established.

G. WEAPONS STORAGE

Perhaps the biggest hurdle to overcome is the problem of weapons storage encountered by the NADEPs. Virtually every government facility has extremely limited or no storage facilities for the ordnance portion of the missile. One of the major reasons for creating the I level was the inability of the NADEPs to handle the warheads and/or fuels contained within the missile [Ref. 11]. If one is considering combining these two, then all the political, economic and environmental ramifications of ordnance handling must be carefully weighed. With today's climate, the political problems are paramount, and must be heavily weighed in any decision.

H. PAPERWORK "COMPATIBILITY"

Information reporting systems will need to be standardized. New forms must be developed that are compatible with, and endorsed by, all concerned. The current problem of incompatibility between NAVAIR and NAVSEA paperwork will need to be eliminated. Even without further action in the area of a combined I/D level facility, the

standardization of paperwork will go a long way toward improving efficiency and relations between the two commands.

I. MISSILE MAINTENANCE UNITS

If a combined I/D facility is developed, continuation of the Missile Maintenance Unit (MMU) should be considered. Although initially regarded as an experiment, MMU1 has proven itself to be a capable repair facility that has the potential for realizing large cost savings. Even if limited to the most minimal tasks of inspection and Weapons Repairable Assembly (WRA) replacement, the savings in transportation costs alone are substantial. Consider the cost of transportation from the Philippines to the United States, then couple that with the delays encountered in even a dedicated transportation system, and one can easily see that the MMU has the potential for realizing large savings in the missile repair pipeline, both in dollars and inventory and readiness figures.

J. TECHNOLOGICAL ADVANCEMENT

As new technological improvements are made, some of the work currently performed at the I level could be assumed by the Organization level. For example, Built In Test Equipment (BITE) could be expanded to include a "plug-in" portable unit capable of testing some of the missile's subsystems. Such a capability at the O level could enable the ship or squadron to increase the Serviceable In Service

Time (SIST) of the missile, further reducing the need for the unit to be inducted into the maintenance pipeline. Again the effect would be lower transportation costs and higher readiness percentages. Although still undeveloped, such electronic capabilities are advancing at an ever increasing rate. Since retrofit costs are high, the decision maker should seriously consider the use of such emergent technology when evaluating the alternatives.

K. CONCLUSION

This chapter has concerned itself with the possibility of combining intermediate and depot level maintenance functions. Prior to making the decision about which functions to combine, several factors must be considered. The major ones were dealt with in this chapter.

Compared with some of the factors dealt with in preceding chapters, many of the elements discussed here may seem trivial, and perhaps they may be if considered individually. However, most of the points mentioned are interrelated and it is this interrelation that produces a substantial impact upon the economic and strategic outcome of the decision between a separate or combined facility.

VII. COST DETERMINATION

A. SYSTEM REQUIREMENTS

Before the decision-maker can reasonably compare the alternatives on a cost basis, he should determine the minimum requirements of the system. For the most part, this equates to the average production capacity necessary to meet the missile repair and inspection demand. This demand is essentially a function of missile inspection intervals, mission readiness requirements, unscheduled failures and inventory size. The following formula is offered to determine the minimum required system production rate per missile type:

$$P = \frac{(R \times I)}{s} + a,$$

where, per missile type,

P = production rate
R = readiness level
I = missile inventory
s = inspection interval(SIST)
a = the rate of unscheduled returns due to missiles failing BITE checks, damaged through mishandling, etc.

Average required turn-around-time can be obtained with the following formula:

$$Rtat = \frac{((1-R) \times I)}{P},$$

where Rtat = average required turn-around-time.

The above formulas assume that the work is level loaded. In reality, operational training cycles will produce peaks and valleys in the demand. Therefore, they should be viewed primarily as a means to establish a baseline. The decision-maker will probably wish to configure the system to meet higher than average demand. Otherwise, if productivity cannot meet periods of heightened demand, mission readiness will decrease until production can catch up.

It should be noted that the turn-around-time begins when the SIST expires or the defective unit is discovered and ends when the missile is made available to the fleet. Therefore, logistics and administrative delay time must be taken into account when the system is configured to meet the required turn-around-time.

The production effort itself will consist of two basic functions which are 1) the inspection and return to the fleet of missiles that require no further maintenance and 2) the repair of missiles that fail initial inspection or require refurbishing. Since the missiles that pass inspection constitute roughly 80% of the production quota, the effort to design the production capacity can primarily focus on those missiles that require further maintenance.

In addition to production requirements, there are other requirements that can affect the cost data such as surge capacity or the acceptable vulnerability to attack.

B. INDIVIDUAL COST ELEMENTS

Once minimum requirements have been defined and the decision maker has compiled the attributes of the system alternatives, he must then determine their costs for comparison. These costs can be grouped into four basic categories. [Ref. 29: pp. 416-470]

The first category is composed of direct costs and are generally straightforward. An example would be the procurement cost of a standard piece of equipment. The second category, indirect costs, are somewhat less obvious but can still be determined for accounting purposes. Administrative costs would fall under this category. Many of the costs for the missile maintenance system can be categorized as indeterminate. For example, undeveloped technology and obsolescence will eventually have definite costs but cannot be determined at the time of system acquisition. Finally, intangible costs, such as surge capability and strategic vulnerability, that defy quantification, are an essential part of the problem.

1. Direct Costs

The following elements of the missile maintenance facility are considered direct costs and can be included into the cost matrix (Figure 2, Chapter I) at their face values:

a. Land and buildings.
b. Alterations to present facilities.
c. Transportation rates.
d. Utilities.
e. Non-developmental hardware and supplies.
f. Salaries and wages of shop personnel.

2. Indirect Costs

Other elements of the missile maintenance facility can be quantified but are not available in the form of price lists, rate schedules or regional wage indexes. These costs include:

a. Corporate office overhead.
b. Contract costs.
c. Technical data packages.
d. Services from support activities.

3. Indeterminate Costs

Relative to direct and indirect costs, indeterminate costs are much more difficult to obtain and must be estimated. These costs will introduce the greatest amount of uncertainty into the optimization problem because they will eventually materialize as actual, measurable dollar amounts but cannot be accurately determined until they have occurred.

The following elements are the most obvious indeterminate costs that have been identified in this thesis:

a. Administrative errors.
b. Contractor risk.
c. Cost overruns from time delays.
d. Costs of idle assets.
e. Theft.
f. Accidental loss.
g. Union demands.
h. Obsolescence.
i. Undeveloped technology.

4. <u>Intangible Costs</u>

Intangible costs do not lend themselves to quantification. However, each choice will influence the degree to which these costs occur and they can be compared between choices.

The following would be included in this category:

a. Flexibility of management.
b. Vulnerability to attack.
c. Social climate and work ethic.

C. CONCLUSION

The degree to which the decision maker effectively arrives at an optimal choice will be greatly influenced by his ability to determine accurate cost data. Some elements are fairly straightforward. Off-the-shelf equipment and real estate costs can be determined through consumer price lists or inquiry. Other costs, such as procurement of undeveloped, high technology test equipment must be estimated and can contribute significantly to the life-cycle-cost. Finally, costs such as obsolescence will only be "best guesses" derived through expert opinion.

The decision maker must also decide when he has collected enough data. It is possible to spend time and money ferreting out costs that are immaterial. Sensitivity analysis should be used throughout the collection process to indicate a reasonable level of research.

It has been estimated that 60% of a system's life-cycle costs are determined during early program planning and conceptual design [Ref. 18: p. 66]. For the relatively small amount of resource required for cost analysis, significant savings can be realized throughout the life of the maintenance facility.

VIII. CONCLUSIONS AND RECOMMENDATIONS

This thesis has addressed the five primary issues of ownership, management, number of repair sites, test equipment configuration and maintenance organizational structure of a prospective air launched missile maintenance program for the U. S. Navy. It is assumed that when the Request For Proposal is issued, the level of detail will be much more complete than that presented in this thesis. However, we have attempted to deliver a conceptual road map for comparison of available alternatives.

If the reader is to gain any appreciation for the nature of the missile maintenance facility, it is imperative that he view it as a system. Just as the airframe, powerplant and avionics of an aircraft require careful design and integration, so must the "components" of the missile maintenance system. The configuration of each of the five basic sub-units discussed in this thesis will have a profound effect upon the make-up of the other four.

Obviously, constraints on the system will determine much of its structure. Fiscal limits must be observed and, though less defined, political elements cannot be ignored. Revision of existing organizational control, such as the NAVSEA/I-level and NAVAIR/D-level cognizance, would entail significant change.

Calculating an optimal solution within the constraints is itself a major undertaking. An appropriate range for the variables should be defined and significant cost elements must be segregated from trivia. Risks associated with new technology must be weighed against known variables having less potential. Finally, strategic values must somehow be matched with dollar thresholds.

Input data values should be as accurate as possible. Bearing in mind the systemic nature of the problem, missing or poorly derived estimates of any number of variables can completely change the outcome.

A significant number of the issues addressed in this thesis entail indeterminate costs. Numerous statistical methods for indeterminate cost estimation have been developed, such as parametric analysis and the delphi technique. Each method has its own strengths and weaknesses and it is suggested that the reader refer to Risk Assessment Techniques, A Handbook for Program Management Personnel, Defense Systems Management College, Fort Belvoir, Virginia, for further information.

Another excellent source for detailed guidance in conducting cost comparisons is DoD Instruction 4100.33-H, DOD In-House Vs. Contract Commercial and Industrial Activities Cost Comparison Handbook. This document addresses aspects such as those listed above and provides a step by step outline for the comparison process.

Some significant variables simply cannot be determined. A drastic jump in fuel prices similar to that experienced in the early 1970s would impact transportation costs and skew the decision factor for geographic locations and transportation modes. Future appropriations by Congress can vary considerably from one administration to the next, affecting the acquisition strategy of hardware and real property. Countermeasures developed by adversarial nations which render current weapons systems obsolete become increasingly possible as their technology advances. These unknowns leave the decision maker little choice but to satisfice.

Though beyond the scope of this thesis, one issue that bears mention is how well the current missile maintenance policy would satisfy the needs of the fleet with the funding that would be used for an omnibus facility. Whether actively or by default, the decision will ultimately be made to either proceed or not proceed with a missile maintenance program that is fundamentally different from the one now existing. It is strongly recommended that, as a minimum, the issues compiled in this thesis be thoroughly examined before a final course is set.

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